How strong can the coupling of leptonic photons be?

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Abstract

Consequences of possible existence of leptonic photon are considered for a range of values of leptonic charge. In the case of a strong Coulomb-like leptonic repulsion between electrons the existence of ordinary condensed matter is impossible: antineutrinos cannot neutralize this destructive repulsion. The upper limit of leptonic charge is inferred from the Eötvös type experiments. If however there exist light stable scalar bosons with leptonic charge (e.g. singlet antisneutrinos) they may neutralize the electron repulsion. Possible experimental manifestations of such leptonic bosons in gases and condensed matter are briefly discussed.

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1 Introduction

A possible existence of leptonic photons coupled to leptonic charge e_l analogously to the coupling of the ordinary photons to the electric charge e has been discussed a long time ago [1] following a paper of Lee and Yang [2] on hypothetical baryonic photons. It was shown (see also [3]), that the coupling $\alpha_l = e_l^2/4\pi$ must be very small ($\alpha_l < 10^{-49}$ as compared to $\alpha = 1/137$) in order to comply with the results of the experiments [4] - [6] testing the independence of gravitational acceleration on atomic number of the material of which a pendulum is made of. This upper limit was derived in [1] assuming that the neutralization of leptonic charge of the Earth and the Sun by the electronic antineutrinos is negligible.

A few years later α_l of the order of $10^{-8} - 10^{-9}$ was postulated by arguing that the neutralization of the Earth's leptonic charge by $\bar{\nu}_e$'s is almost complete [7],[8]. This claim was critically analyzed in ref. [9].

First, it was noted that $\alpha_l \leq 10^{-11}$ from the experiments on $\nu_e e$-scattering. (This had been pointed out to the author of ref. [9] by V.B.Geshkenbein and B.L.Ioffe. At present this experimental limit must be at least an order of magnitude better).

Second, it was argued that due to leptonic repulsion between atoms (because of leptonic charge of the latter) the ordinary matter would be unstable and a process of granulation would take place. Each granule would present a kind of an "atom", the nucleus of which would consist of a grain of ordinary matter and the "atomic shell" – of electronic antineutrinos. The maximal, critical radius r_c of a grain would be determined by equilibrium between the leptonic repulsion, proportional to r^3, and ordinary chemical short range attraction, proportional to r^2.

Let us denote N_c the number of ordinary atoms in a grain of a critical size. Then

$$\frac{(ZN_c)^2 \alpha_l}{(aN_c^{1/3})^2} \sim \frac{\alpha^2 \cdot N_c^{2/3}}{a^2} \tag{1}$$

where a is the size of an ordinary atom, Z is the number of electrons in it, $r_c \sim aN_c^{1/3}$, and α^2/a^2 stands for a crude estimate of the Van-der-Waals force; as an upper limit for a chemical force one can use α/a^2. (In order to derive Eq. (1) consider two halves of a grain of radius r_c. The l.h.s of Eq. (1) is the force of Coulomb-like leptonic repulsion of the two halves, while the r.h.s is the chemical force of their surface attraction.) From Eq. (1) it follows that a grain is stable if $N < N_c$, where

$$N_c \sim \left(\frac{\alpha^2}{Z^2 \alpha_l} \right)^{3/2} \quad , \tag{2}$$

With $Z \sim 10$, $\alpha_l \sim 10^{-12}$, one gets $N_c \sim 10^9$ and $r_c \sim 10^{-5}$ cm. For $m_{\bar{\nu}_e} = 1$ eV the radius of the inner "atomic" shell would then be $1/(ZN\alpha_l m_{\bar{\nu}_e}) \sim 10^{-3}$ cm while that of the outer shell $1/(\alpha_l m_{\bar{\nu}_e}) \sim 10^7$ cm. Note that even the inner shell is much larger than

the "nucleus" and inside the nucleus there is practically no neutralization of the leptonic charge of atoms by antineutrinos.

Third, ref. [9] contained a simple argument due to Ya.B.Zeldovich, that an $\bar{\nu}_e$ cloud neutralizing electrons in the Earth cannot be in equilibrium. Due to the Pauli principle, the momentum p of $\bar{\nu}_e$ must be tens of keV (if their average density is equal to the electron density), ($p \sim Z/a$, where $a \sim 10^{-8}$ cm is the diameter of an atom and Z - the number of electrons in it (for the Earth $Z \sim 20$)). For a light $\bar{\nu}_e$ with $m_{\bar{\nu}_e} < 100$ eV the kinetic energy is $E_{\rm kin} = p$. At the same time the average potential energy U of attraction to an atom is $Z\alpha_l/a = Z(\alpha_l/\alpha){\rm Ry} \sim 10^{-8}$ eV. Thus, $T >> |U|$ and the macroscopic condensed bodies are explosive. In fact it is better to say that in normal conditions they do not form because the binding energy, $\sim 10^{-8}$ eV, is much smaller than the characteristic energy of neutrinos. The system is more like an electromagnetic plasma at temperatures higher than the hydrogen recombination temperature. We consider the mechanism of instability in some detail in Sec.2.

The final remark of ref. [9] referred to a hypothetical situation when the leptonic charge of atoms is neutralized by a special kind of leptonically charged bosons. In this case the leptonic charge of the earth could be compensated. "It is interesting to find out at what values of α_l and of the lepton boson mass, the existence of the condensate of such bosons does not contradict the established physical, chemical and mechanical properties of the matter" [9]. The bosonic case which was recently considered in ref. [10] is discussed in Sec. 3.

2 Condensed matter cannot be neutralized by antineutrinos

Let us consider neutralization by $\bar{\nu}_e$ of the leptonic charge of electrons in a macroscopic body with the density of electrons $n_e(\vec{x})$. We start with assuming that the system is in a state of equilibrium and will prove that this assumption is wrong.

The profile of the antineutrino density $n_{\bar{\nu}}(\vec{x})$ can be found by means of the Thomas-Fermi equation, which in this case is derived as follows. Let $\phi(\vec{x})$ be the potential energy of one antineutrino in the potential of the field associated with the leptonic charge. The behavior of $\phi(\vec{x})$ is determined by the Poisson equation

$$\Delta\phi = 4\pi\alpha_l(n_e - n_{\bar{\nu}}) \tag{3}$$

For a degenerate antineutrino gas the density $n_{\bar{\nu}}$ is given by the Fermi momentum p_F of the $\bar{\nu}_e$ as [1]

$$n_{\bar{\nu}} = \frac{1}{6\pi^2}p_F^3 \quad . \tag{4}$$

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[1]We assume that $\bar{\nu}_e$ is two-component. The assumption of the degeneracy will be discussed below.

The condition of equilibrium for the antineutrino gas is that the sum of the kinetic and the potential energy should be a constant, independent of $\vec{x}$. For a relativistic antineutrino, $p_F \gg m_{\bar{\nu}}$, the latter has the form

$$p_F + \phi = c \ . \tag{5}$$

The constant c is fixed by the boundary condition at infinity: $c = 0$. Thus the Poisson equation (3) can be rewritten in a closed form in terms of the position-dependent Fermi momentum p_F:

$$\Delta p_F = -4\pi \alpha_l \left(n_e - \frac{1}{6\pi^2} p_F^3 \right) \tag{6}$$

If the profile $n_e(\vec{x})$ of the electron density is parametrized in terms of a characteristic value n_0 as $n_e(x) = n_0 f(\vec{x})$ with dimensionless function $f(\vec{x})$, the equation (6) can be rendered in the form

$$\Delta u(\vec{x}) = \mu^2 (f(\vec{x}) - u^3(\vec{x})) \ , \tag{7}$$

where $u(\vec{x}) = p_F(\vec{x})/(6\pi^2 n_0)^{1/3}$ is the dimensionless ratio of the momentum p_F for neutrinos to an effective Fermi momentum, characterizing the electron density n_0, and

$$\mu = \left(\frac{4\pi \alpha_l}{(6\pi^2)^{1/3}} \right)^{1/2} n_0^{1/3} \tag{8}$$

is the corresponding "mass parameter".

In order to estimate the magnitude of the quantities involved and also to justify the assumptions about the degenerate gas of relativistic antineutrinos, let us consider a solid body of characteristic size L, with a uniform density $n_e = n_0 \approx 10^{25} \text{cm}^{-3}$, which corresponds to an effective Fermi momentum $p_0 = (6\pi^2 n_0)^{1/3} \sim 1.7 \cdot 10^4$ eV, which is much larger than both the possible neutrino mass and a possible temperature in terrestrial conditions. The mass parameter μ then has the characteristic value $\mu \simeq 8 \cdot 10^{-3} \sqrt{\alpha_l/10^{-12}} \text{eV} \simeq \sqrt{\alpha_l/10^{-12}} (3 \cdot 10^{-3} \text{cm})^{-1}$. In this model example the function $f(\vec{x})$ is $f(\vec{x}) = 1$ inside the body and $f(\vec{x}) = 0$ outside the body. If the size of the body L is large, $L \gg 1/\mu$, the solution of the equation exponentially approaches $u = 1$ from the surface inwards, the scale in the exponent being set by the skin depth $1/\mu$. Therefore, the leptonic charge of the bulk of the body is completely neutralized ($u = 1$), except for the skin layer. Outside the body the solution for $u(\vec{x})$ dies down as a power of distance, if vacuum is assumed at infinity. (More precisely, one should expect an exponential Debye screening by the sea of cosmic antineutrinos, even if they are massless. The screening length is $D \sim (E_{\bar{\nu}}/\alpha_l n_{\bar{\nu}})^{1/2}$ where $E_{\bar{\nu}}$ is the characteristic antineutrino energy and $n_{\bar{\nu}}$ is their number density. For the average cosmological values $n \simeq 100$ cm^{-3} and $E \simeq 2$ K the screening length is $D \simeq 10^5$ cm. By the way, this means that the outer shell of an "atom" considered in Introduction should be much smaller due to the Debye screening. For massive nonrelativistic neutrinos the galactic number density

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may be larger and kinetic energy E smaller, so correspondingly the screening length D would be considerably smaller. The result depends upon velocity distribution and the neutrino mass (for more details see Sec. 3). For the neutrino gas with the parameters considered in this Section the results qualitatively do not change due to large Debye length $D \sim 1/e_l E_{\bar{\nu}}$.)

Thus, one is tempted to conclude that the bulk leptonic charge of macroscopic objects could be neutralized, unless the dimension L is small in comparison with the skin depth, $L \ll 1/\mu$. (One can readily see that for objects whose all three dimensions are of the same order, the latter condition is equivalent to an upper bound on the total number of electrons N_e in the object: $N_e \ll \alpha_l^{-3/2}$. For such objects the antineutrino density inside them is small: $n_{\bar{\nu}} \ll n_e$, so that local neutralization of the leptonic charge does not take place as was already discussed in the Introduction).

Let us now consider large objects with $L \gg 1/\mu$. In the previous discussion it was assumed that the electron density $n_e(\vec{x})$ was fixed by the electron binding in atoms and the overall stability of the body was ensured by the elastic forces, i.e. the back reaction of the pressure of the antineutrino gas on the stability of matter was ignored. We will show now that for ordinary substances this assumption is in fact violated by many orders of magnitude independently of α_l, provided that the condition $L \gg 1/\mu$ is satisfied. Indeed, in the bulk of the body $n_{\bar{\nu}} = n_e$, while exactly on the surface $(n_e - n_{\bar{\nu}})/n_e = O(1)$. For the pressure of the antineutrino gas inside the body we have

$$P \simeq n_{\bar{\nu}}^{4/3} \simeq n_e^{4/3} , \tag{9}$$

Therefore, the skin layer experiences the pressure difference of the order of $n_0^{4/3} \approx 7 \cdot 10^{15}$ Pa. The highest pressure sustained by known materials is about $1.5 \cdot 10^9$ Pa, while for most solids it is typically $10^7 - 10^8$ Pa, not even to mention liquids. Thus it is impossible to stabilize the neutrino pressure by elasticity of materials.

There is another, more simple way to derive the same results. Let us consider the "capacitor" formed by atoms and $\bar{\nu}_e$ in the skin layer. The pressure P of the degenerate antineutrino gas is balanced by the leptonic attraction between oppositely charged layers with the surface leptonic charge density $\sigma = e_l n_{\bar{\nu}} b$, where b is the thickness of the skin. Then the attraction force per unit area is

$$\frac{F}{S} = 4\pi\sigma^2 = 4\pi\alpha_l n_{\bar{\nu}}^2 b^2 \tag{10}$$

On the other hand, $F/S = P$ with $P = p_F^4/24\pi^2$ and $n_{\bar{\nu}} = p_F^3/6\pi^2$. From this we get

$$p_F^4/24\pi^2 = 4\pi\alpha_l \left(\frac{p_F^3}{6\pi^2} \right)^2 b^2 \tag{11}$$

$$b = \frac{1}{p_F} \sqrt{\frac{3\pi}{8\alpha_l}} = \frac{1}{4} \left(\frac{6}{\pi} \right)^{1/6} n_e^{-1/3} \alpha_l^{-1/2} , \tag{12}$$

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which is very close to the previous estimate of skin thickness $1/\mu$ with μ from Eq.(8) (differs by factor 2).

Note that if we rewrite n_e in terms of the Bohr radius $a_0 \simeq 0.5 \cdot 10^{-8}$ cm,

$$n_e \simeq \frac{3Z}{4\pi a_0^3} \quad , \tag{13}$$

then

$$b \sim \frac{a_0}{\sqrt{\alpha_l}} Z^{-1/3} \tag{14}$$

For $Z = 10$ and $\alpha_l = 10^{-12}$ we find $b \simeq 10^{-3}$ cm.

Therefore the source of nonequilibrium is the thin skin layer. The electrons in the skin leptonically repel each other, so that parts of the skin are explosively peeled off. This process would continue till the whole body would blow up producing small pieces of dust with the size evaluated in the Introduction. For more compact bodies gravitational attraction might dominate like that in white dwarfs, where gravity compensates Coulomb repulsion of ions.

By decreasing α_l we get an increased thickness of the skin. But the peeling pressure

$$P \simeq \left(\frac{a_0}{\sqrt{\alpha_l}}\right)^2 \cdot \frac{\alpha_l}{Z^{2/3}} n_e^2 \sim \frac{Z^{4/3}}{a_0^4} \tag{15}$$

remains constant as long as $L\mu \gg 1$.

The atomic forces are thus insufficient to compensate the repulsion of electrons. Therefore one has to seek for some outer force to keep the system bound. The only force conceivable in terrestrial conditions is the gravity, it gives the binding energy around $\alpha_N N_\oplus / R_\oplus$ per electron where $\alpha_N = G_N m_b^2 \sim 10^{-38}$, and $N_\oplus \sim 10^{51}$ is the number of baryons in the Earth (which is approximately twice the number of electrons), $R_\oplus \simeq 10^9$ cm being the Earth radius. (We substitute the baryon mass m_b in this estimate and not m_e, since actually the gravity binds baryons whereas electrons are coupled to them by ordinary electric field - cf. below for the case of bosons). We find that the gravitational binding energy is four orders of magnitude lower than required. Thus antineutrinos with density $n_{\bar{\nu}} = n_e$ would not stay inside the Earth even if by some miracle they had been pumped in.

As the electrons in the Earth and in the Sun cannot be neutralized by antineutrinos the upper limit on α_l is valid, derived in ref. [1] on the basis of the Eötvös-type experiments.

3 Sneutrinos in the atmosphere and in condensed matter

Let us consider now the case of bosonic leptons, e.g. $\tilde{\bar{\nu}}$: antisneutrinos [2], assuming that their mass is very small: of the order of 1 eV. This possibility was raised in the paper [10].

The authors of [10] suggest to estimate the effect of the compensation by using the same Poisson equation (3),

$$\Delta\phi(\vec{x}) = 4\pi\alpha_l(n_e(\vec{x}) - n_l(\vec{x})) , \qquad (16)$$

where n_l denotes the number density of the sneutrinos $\tilde{\bar{\nu}}$ the distribution of which was assumed to obey the Boltzmann law

$$n_l(\vec{x}) = n_0 \exp(-\phi(\vec{x})/T) . \qquad (17)$$

The equations (16) and (17) are written in analogy with electrodynamics of gases obeying Boltzmann statistics [11, 12]. If we pursue this analogy for the gas of scalar particles with temperature T then we can estimate a characteristic length of screening

$$D \sim (T/\alpha_l n_l)^{1/2} , \qquad (18)$$

This is the well-known Debye radius, defining the range of the screened potential of an electron (see the discussion after Eq. (8) above, cf. e.g. [11, 12] for the case of classical plasma)

$$\phi(r) \sim \exp(-r/D)/r . \qquad (19)$$

The typical distance of interaction of leptons colliding with an atom with Z electrons can be estimated as

$$r_0 \sim \alpha_l Z/T . \qquad (20)$$

This gives the cross-section

$$\sigma \sim r_0^2\Lambda \sim \alpha_l^2 Z^2\Lambda/T^2 , \qquad (21)$$

with Λ being the Coulomb logarithm, $\Lambda \sim \ln(D/r_0)$. Now the time of energy relaxation (or rather of temperature equilibration for $\tilde{\bar{\nu}}$ and ordinary gas) is easily found:

$$t_T = \frac{m_a}{m_l n_l \sigma v_l} \simeq \frac{m_a T^{3/2}}{\alpha_l^2 Z^2 m_l^{1/2} n_l \Lambda} , \qquad (22)$$

where m_a is the mass of an atom. The relaxation time t_T is the order of years for $\alpha_l \simeq 10^{-12}$, $m_l \simeq 1$ eV, $n_l \sim 10^{20}$ cm^{-3} and $T \simeq 300$ K.

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[2]$\tilde{\bar{\nu}}$ – superpartner of the left-handed "sterile" antineutrino, which does not participate in the electroweak interactions; otherwise it would manifest itself in the decays $Z \to \tilde{\bar{\nu}}\tilde{\nu}$ and hence in the invisible width of the Z boson.

If we assume that the lepton charge is compensated on scales larger than D in the thermally relaxed Boltzmann gases of $\tilde{\nu}$'s and of the air in the terrestrial atmosphere then we can show that inevitably a large field E_l appears. This field is necessary to support an approximate equality of concentrations of $\tilde{\nu}$'s and of electrons. Everything is quite analogous to the charge neutrality of plasma in stellar atmospheres which is always slightly violated in the presence of non-electric forces [13]. Let us use the equations of equilibrium

$$\nabla P_a = -n_a m_a g + n_a Z e_l E_l , \tag{23}$$

and

$$\nabla P_l = -n_l m_l g - n_l e_l E_l . \tag{24}$$

where P_a and P_l denote pressures of atoms and leptons respectively and g is the acceleration produced by gravity. We will show now that one cannot satisfy both equations (23) and (24) if $E_l = 0$, i.e. assuming ideal compensation of charges $Z n_a = n_l$, since the gravitational force on atoms is much larger. Yet remembering that the equality $Z n_a \simeq n_l$ is only approximate (though it may be very accurate in fact), one sees that this slight disbalance of charge densities produces non-negligible field E_l. Assuming equal temperatures of atoms and of $\tilde{\nu}$'s we then find

$$m_a g - Z e_l E_l \simeq m_l g + e_l E_l, \tag{25}$$

since the pressure of Boltzmann atoms is $P_a = n_a T$, and the pressure of Boltzmann $\tilde{\nu}$'s is $P_l = n_l T$. Hence,

$$e_l E_l \simeq m_a g/(Z+1). \tag{26}$$

Thus the new force acting on atoms would be comparable to the force of gravity (irrespective of the value of α_l if it is large enough to provide for the dynamic equilibrium). This strong effect could be detected on the bodies with differing ratio $AZ/(Z+1)$, i.e. already in the Newton experiments to say nothing on Eötvös-Dicke experiments. This means that something is wrong in our basic assumptions: either the thermal equilibrium does not hold (due to the low value of α_l), or the Boltzmann approximation to the distribution function is not valid. One should also consider the neutralization of leptonic charge produced by $\tilde{\nu}$'s concentrating in the condensed bodies, since the estimate (26) is directly applicable only to the atoms in the air.

First of all, we have to take into account that the sneutrinos are bosons. Let us estimate the conditions under which the gas consisting of these particles becomes degenerate, that is when the Bose condensate forms. We can find the temperature of condensation in the following way.

The number density of bosons

$$n = \int f d^3 p/(2\pi)^3 \tag{27}$$

where f is the occupation number

$$f = 1/[\exp((E - \mu)/T) - 1] \tag{28}$$

for the thermal equilibrium with temperature T and chemical potential μ. In the presence of the condensate the expression for f is modified:

$$f = (2\pi)^3 C\delta^3(p) + 1/[\exp((E - m)/T) - 1] . \tag{29}$$

The first term corresponds to the particles in the condensate and the second is the normal Bose term with chemical potential equal to the mass. The coefficient C is found from the condition that the particle number density is

$$n = n_l . \tag{30}$$

If the first term in the expression for f is the dominant one, then we can conclude that $C = n_l$. In the case of the Earth's atmosphere $n = n_l = n_e$, where n_e is the number density of electrons. To find the total number of particles we have to calculate the integral

$$n = \int \frac{d^3p}{(2\pi)^3} \left[\exp\left(\frac{E - \mu}{T}\right) - 1\right]^{-1} . \tag{31}$$

The number density of the particles outside the condensate, n_{out}, is given by Eq.(31) with $\mu = m$.

Introducing

$$u = \frac{E - m}{T} , \qquad \beta = \frac{m}{T} \tag{32}$$

we rewrite (31) as

$$n = \frac{m^3}{2\pi^2\beta^{3/2}} \int_0^\infty \frac{(1 + u/\beta)(2 + u/\beta)^{1/2}u^{1/2}}{\exp[u - \beta(\mu/m - 1)] - 1} du . \tag{33}$$

Now, for $T \ll m$, i.e. $\beta \gg 1$, we find the number density of bosons outside the condensate putting $\mu = m$ in (33):

$$n_{\text{out}} = \frac{m^3}{2^{1/2}\pi^2\beta^{3/2}} \int_0^\infty \frac{u^{1/2}du}{\exp u - 1} = \left(\frac{mT}{2\pi}\right)^{3/2} \zeta(3/2) , \tag{34}$$

(see e.g. [16]).

For high temperature, $T \gg m$, i.e. $\beta \ll 1$, we find from (33)

$$n = \frac{m^3}{2\pi^2\beta^3} \int_0^\infty \frac{u^2du}{\exp[u - \beta(\mu/m - 1)] - 1} . \tag{35}$$

and for $\mu = m$

$$n = T_c^3 \zeta(3)/\pi^2 . \tag{36}$$

Thus, keeping in mind that in the Earth's atmosphere at the sea level there are 2.7×10^{19} molecules/cm^3, i.e. the electron concentration is $n_e \simeq 4 \times 10^{20}$, we get for the temperature of condensation

$$T_c = (\pi^2 n_l/\zeta(3))^{1/3} \approx 30 \,\text{eV} . \tag{37}$$

This can be compared to $T = 300\,\text{K} = 0.03$ eV.

In deriving (37) we have neglected processes of pair production and annihilation. In general, at high temperature one has to take into account the presence of antiparticles. If the coupling of pairs to the leptonic photons is strong enough and the dimensions of the system are large enough (so that the antiparticles are trapped) then the concentration of antiparticles $\bar{n}$ is found from (35) by substituting $-\mu$ instead of μ, since the pairs are in equilibrium with blackbody radiation, having zero chemical potential. In this case the condensate is formed when the excess of particles over antiparticles is so big that the maximum possible value of $\mu = m$ is reached. The excess of particles over antiparticles in the limit of small β and small μ/T is

$$\delta n = n - \bar{n} = \frac{m^3}{2\pi^2 \beta^3} \int_0^\infty u^2 \left(\frac{-2\mu}{T}\right) \frac{d}{du} \frac{1}{\exp u - 1} du = \frac{\mu T^2}{3} . \tag{38}$$

The lowest value of the temperature before the formation of condensate can be determined from the equation $\delta n = m T_c^2/3$. At low temperatures, $T \ll m$, the number density of particles n which survived the annihilation is equal to δn, defined by Eq. (38). Hence, for the Earth's atmosphere

$$T_c = \sqrt{3 n_l/m_l} \approx 3 \,\text{keV} \tag{39}$$

for $n_l \simeq n_e$ and $m_l \simeq 1$ eV.

However, we cannot apply the expression (39), which is good for cosmology, to terrestrial conditions, or to conditions in the protoplanetary nebula. For small values of α_l and for temperatures lower than few keV we cannot expect trapping of antiparticles and the equilibrium of pairs with radiation. Here the Eq.(37) is more relevant.

In any case for the small mass of $\tilde{\nu}$'s almost all of them enter the condensate. The fraction of the rest is $(mT/2\pi)^{3/2}\zeta(3/2)/n_l \approx 10^{-9}$. Their pressure depends only on T, and one cannot prove the appearance of nonvanishing field E_l using the same arguments which have led to the result (26).

If the bosons were neutral, the condensate would be collected just in the center of the gravitational potential well [14], i.e. in the Earth's center. In our case one cannot claim this: it is clear that the mutual repulsion of $\tilde{\nu}$'s prohibits their high spatial concentration.

What is the structure of the condensate? In a very rarefied gas the $\tilde{\nu}$'s should form 'atoms' with electrons. The radii of these atoms are by a factor of $(\alpha/\alpha_l)(m_e/m_l)$ larger

than the Bohr radius (see above), i.e. they are in the range from meters through thousand kilometers for $\alpha/\alpha_l \geq 10^{10}$ and for m_l in the range from m_e down to 1 eV. In any case this is much larger than the mean distance between electrons in the terrestrial conditions. Using the arguments of Feynman [15] one can convince oneself that the condensate, i.e. the ground collective state of the scalar particles, must be a quasi-uniform distribution in a self-consistent field E_l, created by the charge density $n_e - n_l$ (where n_l is the total density of $\tilde{\nu}$'s accounting also for the particles outside the condensate.

Let us compare now the problem of the skin layer for bosons with the fermion case, considered in Sec.2. In the boson case, the thickness of the skin is of the order of the Compton wave length of the boson: $b = 1/m_{\tilde{\nu}}$, so that the force of the leptostatic attraction between electrons and antisneutrinos per unit area (which is to be balanced by the pressure due to elastic forces) at the surface is $\alpha_l n_e^2 m_{\tilde{\nu}}^{-2}$. It is easy to see that in this case the force is weaker than in the case of fermionic antineutrinos and decreases with decreasing α_l. The body itself is filled with bosonic condensate of $\tilde{\nu}$'s (at rest). Thus an equilibrium can be reached and the allowed values of α_l depend on $m_{\tilde{\nu}}$.

Let us now estimate the field E_l, accounting for the condensate, using equations (23) and (24). In an isothermal atmosphere one finds a rather weak force

$$e_l E_l = -m_l g \ , \tag{40}$$

which is m_a/m_l times smaller than the gravity for atoms. Given the results of the Eötvös type experiments one may derive a bound on m_l from this.

Consider another, more realistic case: let the atmosphere be non-isothermal and the gravity in (24) can be neglected (if the mass m_l is sufficiently small). Then, since $\nabla P_a \simeq -n_a m_a g$ (the force produced by the field E_l on atoms is negligible) and $P_l \sim (T/T_c)^{3/2}(m_l/T_c)^{1/2}P_a$, we find a crude estimate

$$Z e_l E_l \sim (T/T_c)^{3/2}(m_l/T_c)^{1/2}m_a g \ . \tag{41}$$

For the Earth atmosphere we find the force of the same order (but of the opposite sign) as for the isothermal case. In both cases one may not assume the equality of the temperatures of atoms and scalars. The estimate (41) varies according to the temperature T of the gas of $\tilde{\nu}$'s.

We find that the presence of the condensate strengthens the chances for perfect compensation of charges. One should remember, however, that in a real (non-ideal) Bose-gas, like superfluid helium, an appreciable fraction of bosons remains outside the condensate even at zero temperature. Thus the actual estimate of the force must be somewhere in between the Boltzmann and the ideal Bose estimates considered here. The weakly excited condensate behaves like a superfluid classical liquid and the flow of this liquid must be potential [15, 16]. So, even if one imagines that all macroscopic bodies on the Earth surface are filled with a condensate which screens the electron field E_l inside them (one can imagine an adiabatic process of formation of those bodies embedded in

the uniform cloud of ordinary matter filled with uniform condensate), then one should encounter manifestations of the leptonic charge when the motion of the bodies is not potential and non-adiabatic (like in collisions, etc.).

Perhaps, it is best of all to consider the constraints on α_l on small bodies, like dust grains, in the absence of the condensate in the interstellar (or circumstellar) space, where the gas density is almost vacuum (20 orders lower than in our atmosphere). Let us assume that the constants are such as to give for the simplest electron-scalar "atom" a radius r_a. If we have a dust grain with ZN not screened electrons (N is the number of atoms in the grain, and Z is number of electrons in an atom) then the $\tilde{\bar{\nu}}$'s tend to occupy the "atomic" orbits with radii r_a/ZN. If ZN is very high, then the sneutrinos tend to screen the electrons inside the grain, but if ZN is sufficiently small then all sneutrinos remain outside the grain. E.g. if $r_a = 10^8$ cm and the density of electrons in the grain is 10^{24} cm^{-3}, then at $ZN \sim 10^{12}$ the radius of a grain $r_g \sim 10^{-4}$ cm is of the order of the radius of "atomic" shell. Note that this is an order of magnitude larger than the critical radius r_c at which the grain is disrupted by mutual leptonic repulsion of unscreened electrons (see Introduction). Thus there should be a gap in the spectrum of grain sizes at $r_g \sim 10^{-5} - 10^{-4}$ cm.

It is known [18] that much smaller grains do exist in the interstellar space. There is no convincing evidence that there is a gap in the region of $r_g \sim 10^{-5} - 10^{-4}$ cm, but some models of the interstellar extinction do not exclude that the grain size distribution falls sharply above 0.25×10^{-4} cm (see references in [18]). This can have quite natural explanation without invoking new physics because of grain-grain collisions leading to grain fragmentation. Of course, larger grains must exist and grow in protoplanetary clouds (otherwise, the formation of planets would be impossible). Unfortunately, the theory of evolution of interstellar dust is far from being complete [19]. It would be interesting to explore this question with the new physics discussed here in a broad range of α_l, m_l and to compare this with observations of the interstellar dust.

4   Concluding remarks

Thus we have shown that the old upper limit [1] on α_l is valid if there is no leptonically charged scalar bosons. If such bosons exist, they may screen the leptonic charge of electrons and the situation is less clear. We made our estimates by assuming as reference values $\alpha_l = 10^{-12}$ and $m_l = 1$ eV. It is important to stress that the mass of sneutrinos, m_l, may be much larger. It is very interesting to consider such phenomena as surface tension, surface waves and capillarity (a remark by S.G.Tikhodeev), as well as electrolysis, melting of metals, boiling of water and other phase transitions in the presence of the condensate of leptonic bosons. In this way it would be possible to establish the allowed region on the plane α_l, m_l.

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Acknowledgements

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